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Automated long-term time lapse ERT monitoring of high-latitude permafrost – results of 3 years of monitoring and modeling study

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The importance of long-term, continuous and relatively dense ERT timeseries for improved process analysis in permafrost is well established. However, due to remoteness of sites, logistical constraints and harsh environment, high latitude permafrost presents a particular challenge for long-term ERT monitoring. Furthermore, extremely high grounding resistances hamper acquisition of series of complete freeze-thaw cycles that are needed for comparison with climate observations. In this contribution, we share how we resolved some of the logistical and technical challenges inevitably linked to the ERT monitoring in the Arctic. We also show results of a comprehensive permafrost monitoring project, currently running successfully for more than 3 years.

Since August 2012, we have been operating an automated monitoring station for measuring ground resistivity, water content and temperature at a site near the airport in Ilulissat, West Greenland (69°14'N, 51°3'W, 33 m a.s.l.). The site has a long observation history, starting with geotechnical investigations in late 1970'. The site is located in continuous permafrost zone, with mean annual air temperature -5.1 °C (2003-2012). The active layer thickness at the site is approximately 80 cm, below which ice-rich permafrost is found. The sediment cover consists of postglacial silt and clay marine deposits. These deposits are fully leached in the upper part, with residual salinity increasing with depth. Consequently, deeper parts of the soil profile are technically unfrozen due to freezing point depression. Gneiss bedrock is encountered at 7 m depth (Ingeman-Nielsen et al., 2008).

The monitoring station consist of one ERT profile, measurements of unfrozen water content at two depths in the active layer, measurement of ground temperature in 2 deep boreholes (4 and 6 m) and one temperature probe (length 1.5 m, with 16 sensors every 10 cm) for detailed monitoring of temperature dynamics of the active layer. Additional environmental observations include air temperature, approximate snow depth (using temperature sensors above ground) and ground thermal conductivity.

The ERT profile consists of 64 stainless steel, mesh-shaped electrodes, with spacing of 0.5 m. The mesh electrode shape is result of extensive field and laboratory testing study aiming to optimize the electrode design for long-term ERT monitoring. Automated ERT measurement system consists of a terrameter SAS1000 with electrode selector ES10-64 and an on-site mini computer. The computer controls daily acquisition of grounding resistances for each electrode of the array and a protocol of total 1625 datapoints of Schlumberger and Gradient array. The data are uploaded daily to a server at The Technical University of Denmark via GSM network.

The unfrozen water content is measured at 30 cm and 55 cm depth in the active layer by sensors using frequency domain reflectometry method. A soil-specific calibration equation is used to convert the measured permittivity into volumetric water content.

Comparison of results of joint resistivity, temperature and soil moisture monitoring evidences that changes of subsurface ground resistivity follow closely temperature and water dynamics in the ground. In the frozen period of the year (ca December to June), water content is consistently at its minimum, at 20 %. During this time, however, even relatively small temperature oscillations well below 0 °C produce noticeable changes in ground apparent resistivity. This suggests that notable phase change happens at temperatures as low as -5 to -10 °C and it points to high sensitivity of the ERT to track these changes. During the thawed season, the changes in resistivity are driven mainly by the changes of water content due to water movement in the active layer. After the initial ground thawing throughout the month of June, the ground reaches full saturation at up to 76 %. The thawing is reflected in sharp decrease of ground resistivity throughout the profile. Initial steep increase in soil moisture is followed by a period of drying out, or water runoff, during which the water content declines down to 40 % (while ground temperatures remain positive).

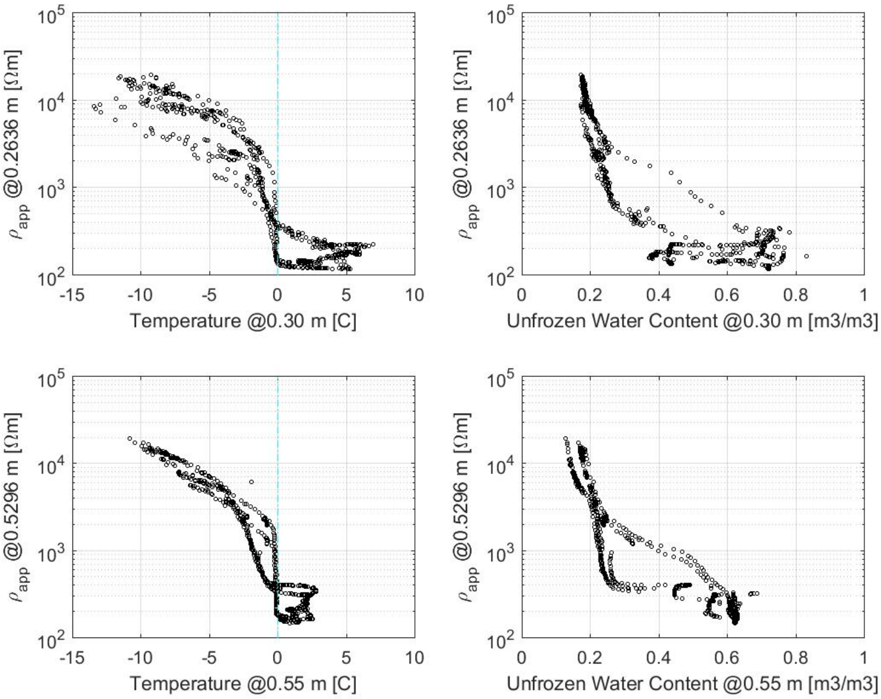

Figure 1: Scatter plots of the apparent resistivity against temperatureand water content at two depth levels in the active layer. Daily average values for 3 years.

This induces increase in resistivity at the top of the active layer, while the resistivity in the deeper portion of the profile steadily decreases as result of propagation of heat wave from ground thawing. The ground then reaches full saturation again during the relatively most humid months of August and September. It is only at this point that the ground resistivity reaches its yearly minimal values.

The ground surface temperature measurements have been successfully used in modeling of ground temperatures throughout the depth of the monitored profile. The 1D-heat model is able to reproduce the measured ground temperatures with mean deviation $\pm 0.2°$. While the full saturation condition at the site is valid (throughout the year except from July to mid-August), the unfrozen water content in the ground can be successfully modeled from ground temperatures (measured or modeled) using soil-specific freezing curve coefficients (Lovell, 1957). As the changes in ground resistivity are intrinsically linked to the changes in the water content, this kind of integrated observation and modeling may pave the way for modeling of ground temperatures using exclusively surface observations (ground surface temperature and ground resistivity).

This ongoing monitoring project demonstrates feasibility and potential of long-term integrated high-latitude permafrost monitoring with focus on electrical and thermal properties of the ground. We present details of the permanent measurement setup and propose improvements to monitoring station design that mitigate the effects of extreme grounding resistances on acquisition of continuous resistivity timeseries. Results of 3 years of daily measurements of ground resistivity, temperature and water content provide insight into processes governing permafrost evolution and allow for modeling of important environmental parameters for which direct observations are difficult to acquire or missing.

References:

Ingeman-Nielsen T., Foged N., Butzbach R., Stuhr Jørgensen A., 2008: Geophysical Investigation of Saline Permafrost at Ilulissat, Greenland. Proceedings of the 9th International Conference on Permafrost, Fairbanks.

Lovell C.W., 1957: Temperature effects on phase composition and strength of partially-frozen soil. Highway Research Board Bulletin 168: 74-95.